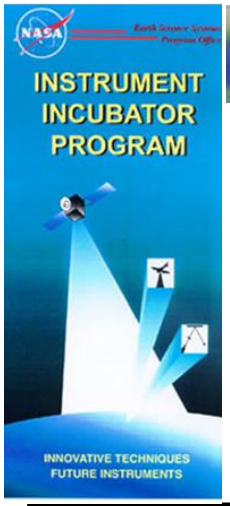
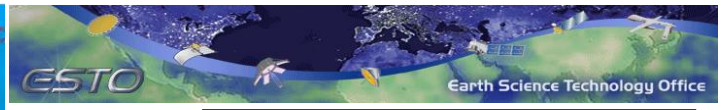
A NEW APPROACH FOR SNOW WATER EQUIVALENT MAPPING USING WIDEBAND SAR/RADIOMETRY

TIM DURHAM, KERRY SPEED, SHELDON DROBOT, ROBERT TAYLOR

First Workshop on NASA SnowEx Results, August 8-10, 2017

NASA ROSES IIP Team - Wideband Instrument for Snow Measurements (WISM)





Principal Investigator
Dr. Tim Durham

PM: Dr. Robert Taylor
PFA: Erin Carrigan
Contracts: Jessica Cantos
S/C Mgmt: Tamara Schimkus

Radar Design & Build — HARRIS

Radar Systems: Kerry Speed
RF Design: Don Rose
Digital Design: Kerry Speed
Software: Art Olsen
Mech Design: Robert Lange
Additional Support:
Diane Caruso

Antenna Fabrication — NUVOTRONICS

Tech. Lead: Dr. Ken Vanhille
Management: Scott Meller

Radiometer/Air Campaigns — NASA

Co-I: Dr. Paul Racette, GSFC
Radiometer Systems: Dr. Quenton Bonds, GSFC
Co-I: Dr. Felix Miranda, GRC
Antenna Test: Dr. Kevin Lambert, Vantage Partners LLC/GRC
Air Campaign: Dr. Lora Koenig, UC

Integration & Test [Harris / BSU] — BOISE STATE UNIVERSITY

Co-I: Dr. Hans-Peter Marshall, BSU

SWE Extraction — THE UNIVERSITY OF MICHIGAN 1817

Science PI/Active Techniques: Dr. Leung Tsang, U. Mich.
Passive Techniques: Ludovic Brucker

Importance of Snow

50-80% of the yearly water supply in the western United States is supplied by the seasonal snowpack. To effectively manage water resources, accurate measurement of the amount of water in the snowpack, the snow water equivalent (SWE), is needed on the very small spatial scales over which the snowpack varies.

Highly Variable Snowpack

NASA WISM ROSES IIP Overview

Harris led a NASA Research Opportunities in Space and Earth Sciences (ROSES) Instrument Incubator Program (IIP)

Developed technology needed to carry out a remote sensing mission to make snow measurements

- Relevant to both airborne and space platforms

The instrument is based on Snow and Cold Land Processes (SCLP) mission concept from Decadal survey

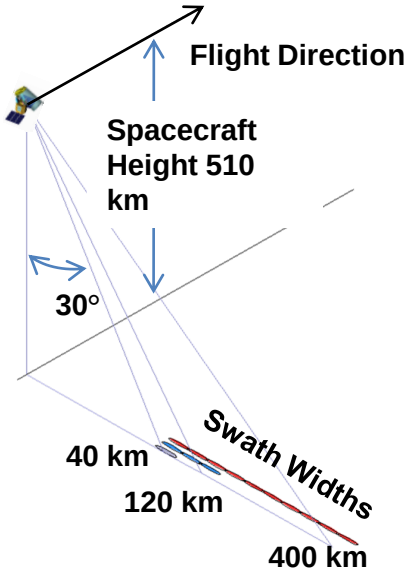
- Four instruments to gather data on snow pack (depth, density, SWE)

Traditional antenna concept uses reflector antennas fed by individual feeds for each frequency/beam

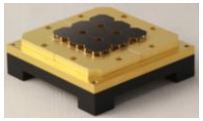
- High size, weight and power (SWaP)

Demonstrated the technology to use a single array feed to support all instruments

- Performance improvement (i.e., co-boresighting)
- Significant SWaP advantages



Existing Technology Feed Concept



WISM Feed

WISM Technical Approach

Combine active and passive sensing technologies in a single instrument

- Built a multi-band radar/radiometer that utilizes the same antenna for six bands from X to Ka band
- Software reconfigurable for many important parameters

Build wideband antenna

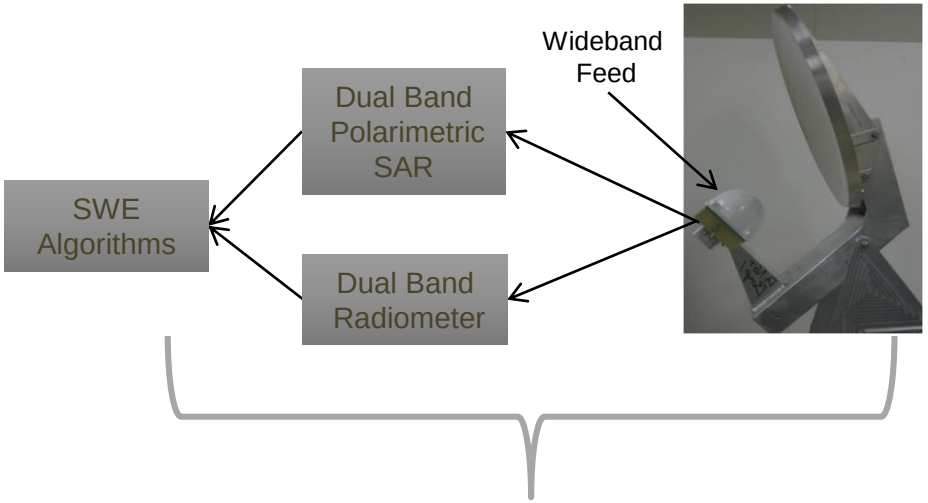
- Implemented first version of Harris' Current Sheet Array (CSA) antenna that operates from 8-40 GHz
- Fabricate the array aperture and RF components in the antenna
- Enhanced version improves performance in many areas

Perform experiments

- Ground-based experiments demonstrated antenna technology is compatible with wideband radars
- Airborne experiments to demonstrate science of snow measurement using active/passive combined sensing

Enhanced Multi-Band/Multi-Function Instrument

- X band (up-down, SAR)
- X band (down, radiometer, enhancement)
- Ku band lower (up-down, SAR, enhancement)
- Ku band upper (up-down, SAR)
- K band (down, radiometer)
- Ka band (down, radiometer)



The Wideband Instrument for Snow Measurements

Wideband Instrument Development

A major part of this IIP effort was developing an instrument consisting of radars and radiometers operating at multiple frequencies all using a single aperture

The goals of this instrument development are:

- Technical: Demonstrate the use of a single wideband aperture for SWE retrieval by building a highly integrated multiband instrument
- Science: Provide data to support development of multiband SWE extraction techniques using both active and passive sensing
- Mission: Build an instrument useful to support future snow science related airborne campaigns

WISM IIP Experiments

Ground Experiments

- Carried out by HP Marshall of Boise State University
- Demonstrated use of wideband antenna for SWE measurements
- Used 2-18 GHz ESM (Harris IR&D) and Alpha-Build (IIP) antennas
- Utilized existing radars at Boise State to successfully measure snow depth and stratification

Snow Depth Measurement using FMCW Radar from Skis and Snowmobile

Three Airborne Air Campaigns

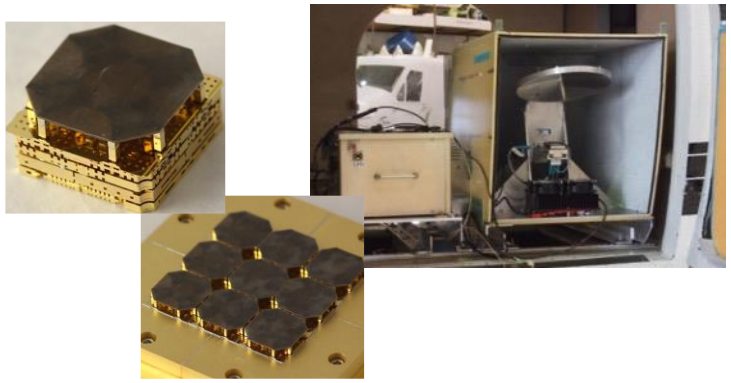
- Used Twin Otter for airborne testing
- Goal to demonstrate use of 8-40 GHz antenna for SWE measurements
  - Data gathered on all six bands
- Multi-band SAR and Radiometer test-bed
  - Enhancements completed
- Three campaigns completed
  - Science quality data from both instruments obtained

TOI Twin Otter Aircraft

Multiple Feed Generations

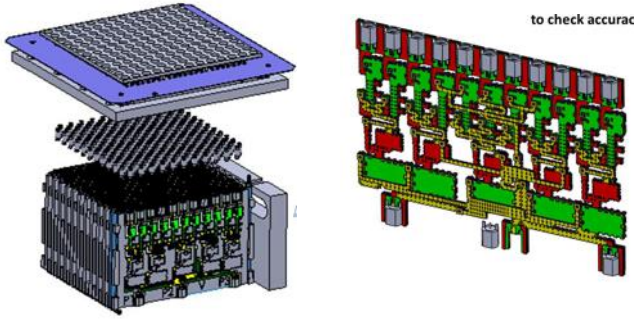
1st Generation

- Modular design
- 6 x 6 elements
- Dual linear polarization



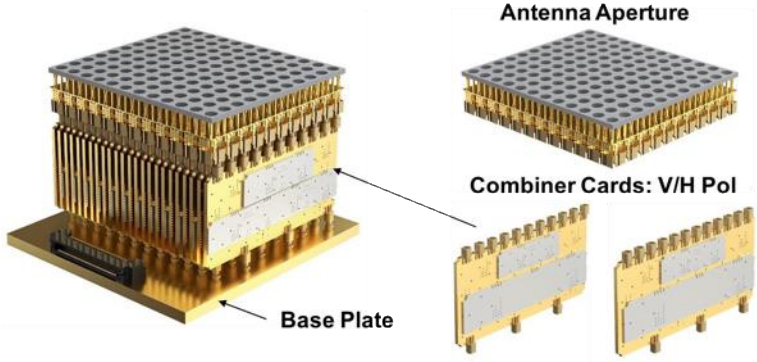
2nd Generation

- 11 x 12 elements
- Integrated filters, improved beam efficiency and lower loss
- Dual-linear across all bands
- Nearing completion now

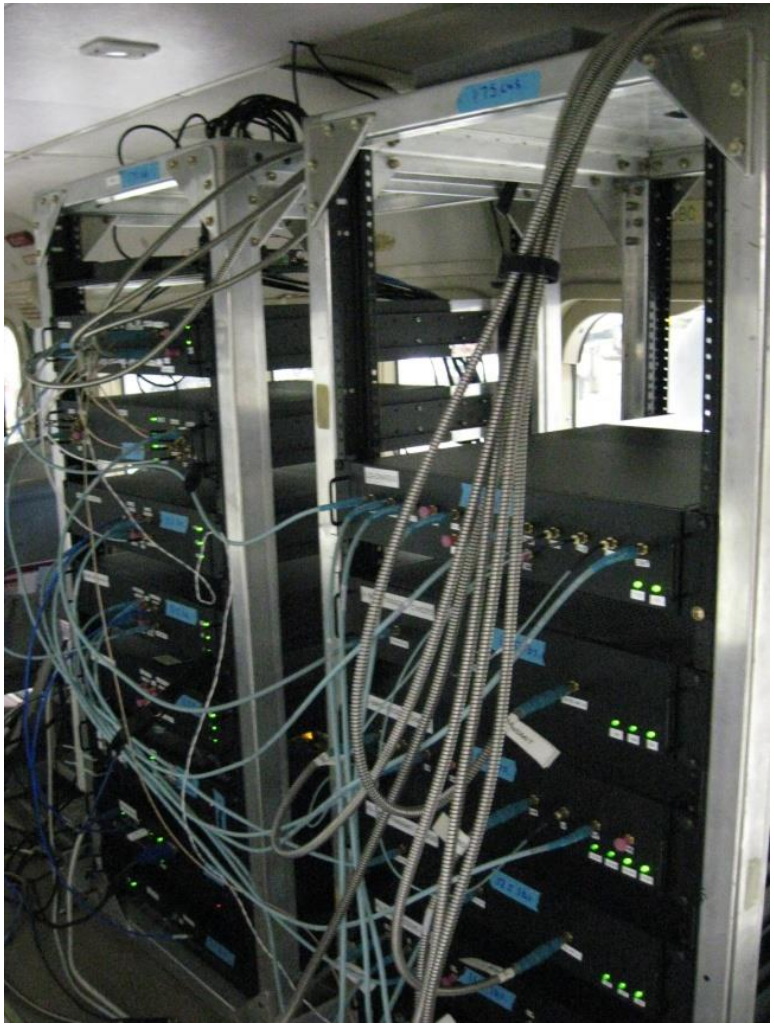


3rd Generation Feed

- Integrated LNAs
- Expandable to line feed
- In process



WISM Installed in the Twin Otter



Enhanced WISM Operating Frequencies

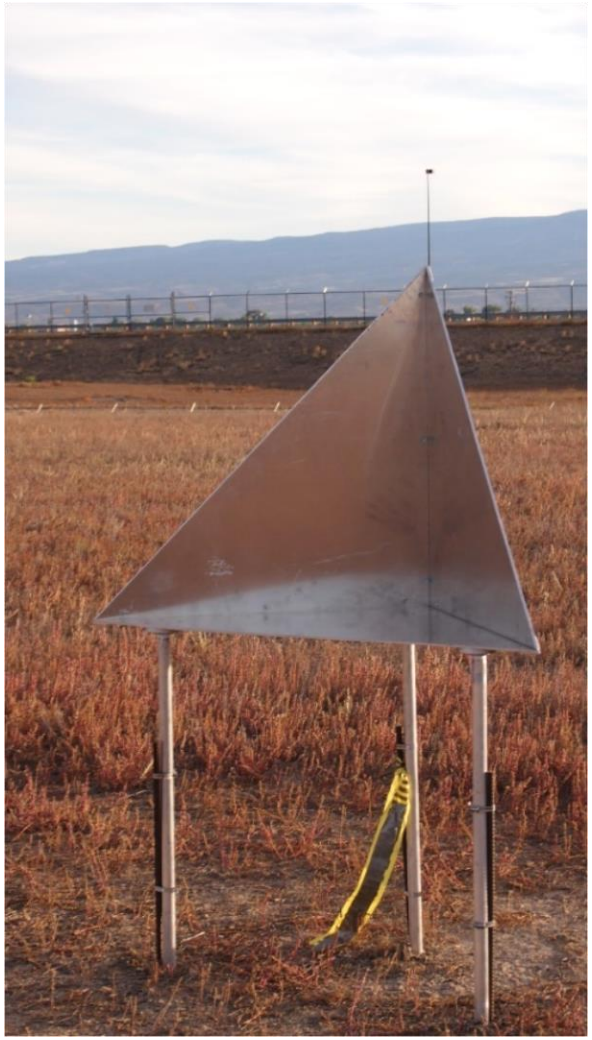
Function	Band	Name*	Center Frequency (GHz)	FCC BW (MHz)	FCC Band Lower (GHz)	FCC Band Upper (GHz)	Polarization
SAR	X	Band 1	9.6	300	9.5	9.8	V Transmit, H/V Receive
Radiometer	X	Band 2	10.65	200	10.55	10.75	H
SAR	Ku-Lower	Band 3	13.6	350	13.4	13.75	V Transmit, H/V Receive
SAR	Ku-Upper	Band 4	17.2	100	17.2	17.3	V Transmit, H/V Receive
Radiometer	K	Band 5	18.7	200	18.6	18.8	H
Radiometer	Ka	Band 6	36.5	1000	36	37	H

Flight Campaign Summary

Three flight campaigns have been completed

- February 2015
  - Four sorties
  - Extensive snow coverage
- October 2015
  - Six sorties
  - Snow-free conditions
- February 2017
  - Seven sorties flown including two science flights
  - Extensive snow coverage
  - Flown in coordination with SnowEx

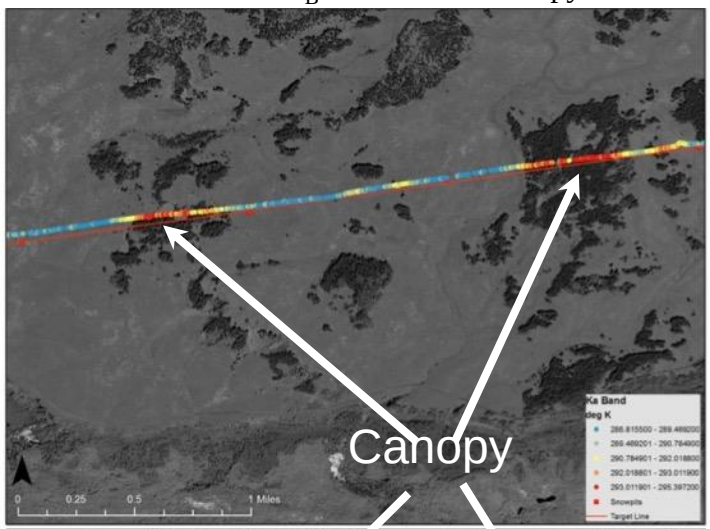
Corner Reflectors Provide Performance Verification and Calibration

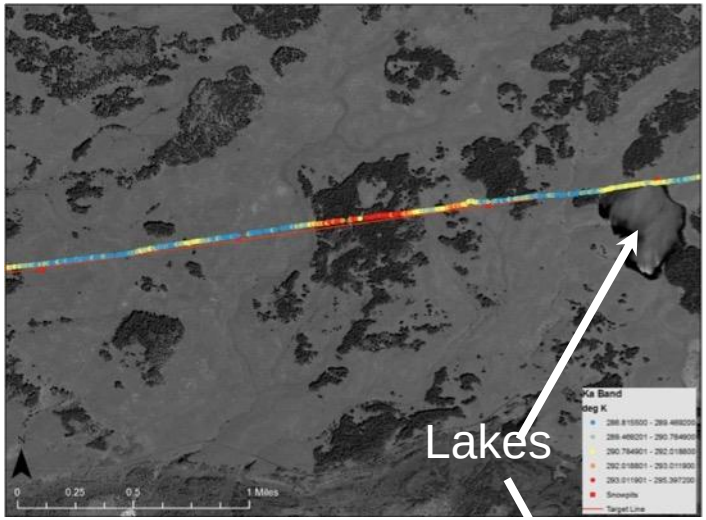


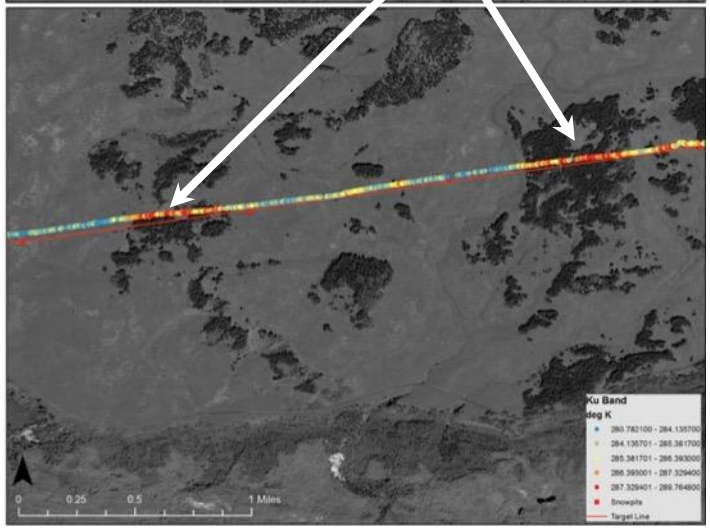
Science Experiment Data Analysis

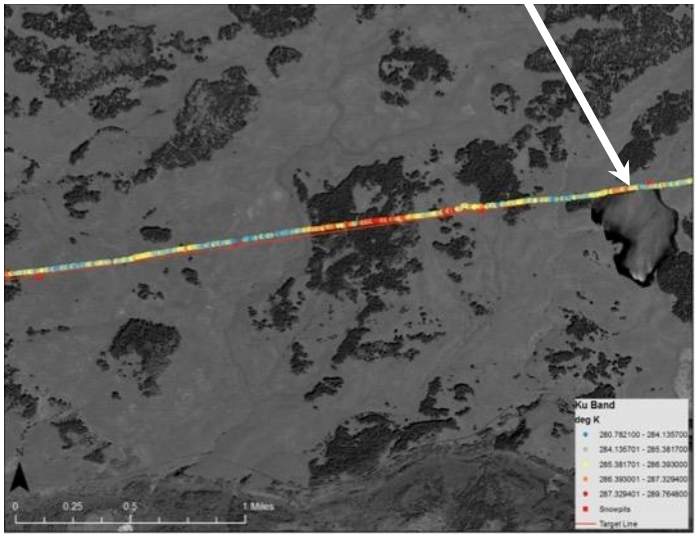
Sci Exp-1 Flt-4 3000ft Pas-1 Eastbound: Tb Over Lakes Plotted on World Map Actual vs Zoomed Scale

T_B of Lakes vs Canopy Demonstrate the Desired Trend Over the Grand Mesa

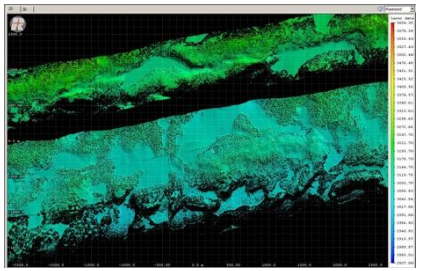








MiniATM Data



Flight Summary – Feb 2017 Campaign

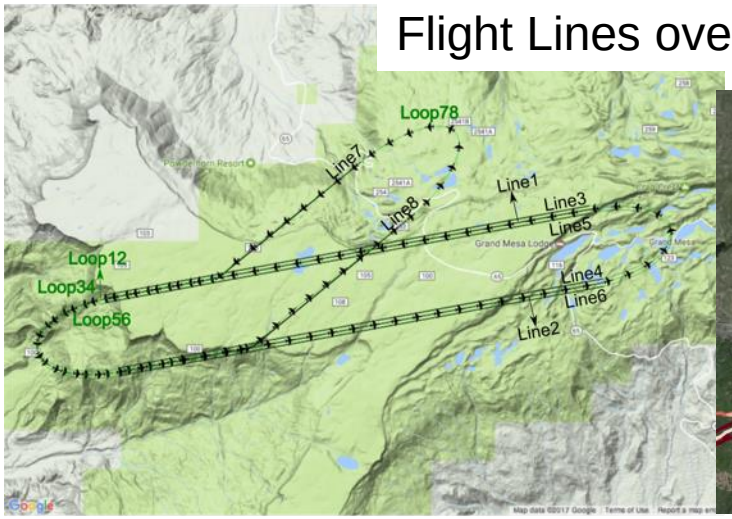
Flt #	Date	Duration	Observation	Radiometer			Radar	MiniATM	Notes
		(hours)	Ft/Location	X	Ku	Ka			
1	2/3/17	0.8	Airport						Local flight over airport to test radar.
2	2/5/17	0.8	Airport						Local flight over airport to test radar.
3	2/5/17	0.7	Airport						Local flight over airport to test radar.
4	2/6/17	0.8	Airport						Local flight over airport to test radar. Radiometer connected; radar X-band H-pol channel disconnected
5	2/8/17	0.5	Mesa Flt						Flight over Grand Mesa aborted due to radar problem
6	2/9/17	1.9	Mesa Flt						Flight over Grand Mesa.
7	2/10/17	1.7	Mesa Flt						Flight over Grand Mesa. Radiometer disconnected; radar X-band H-pol reconnected.

Measurement not attempted

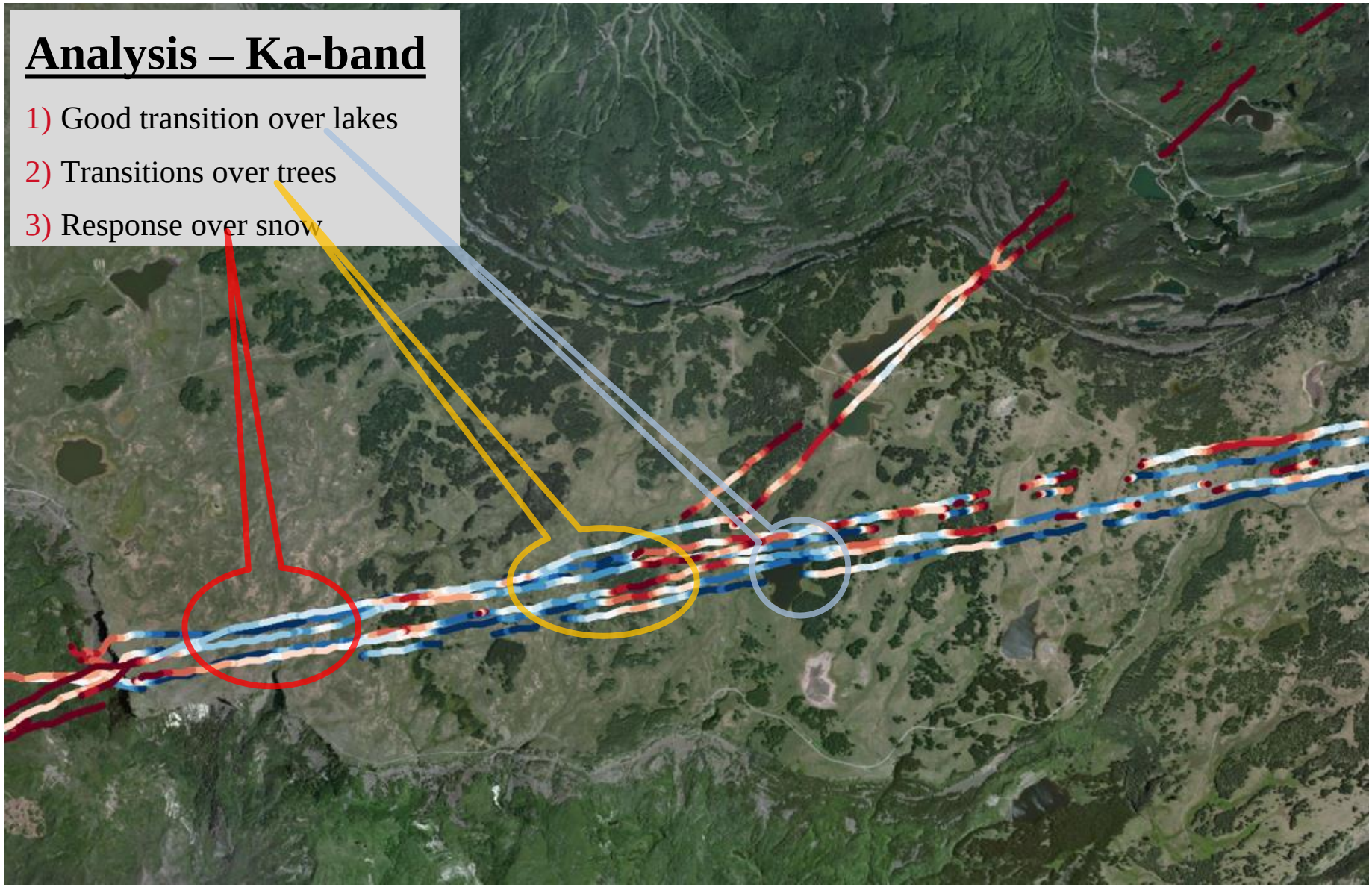
Data Collected

No Usable Data

Flight Lines over the Mesa



Air Campaign III: Radiometer
Preliminary Results: Geolocated Data



SAR Phase II System Description & High Level Requirements

Airborne Strip-map Synthetic Aperture Radar operating at X and two Ku bands with 10 meter resolution

Single polarization transmit (V) dual polarization receive (H,V)

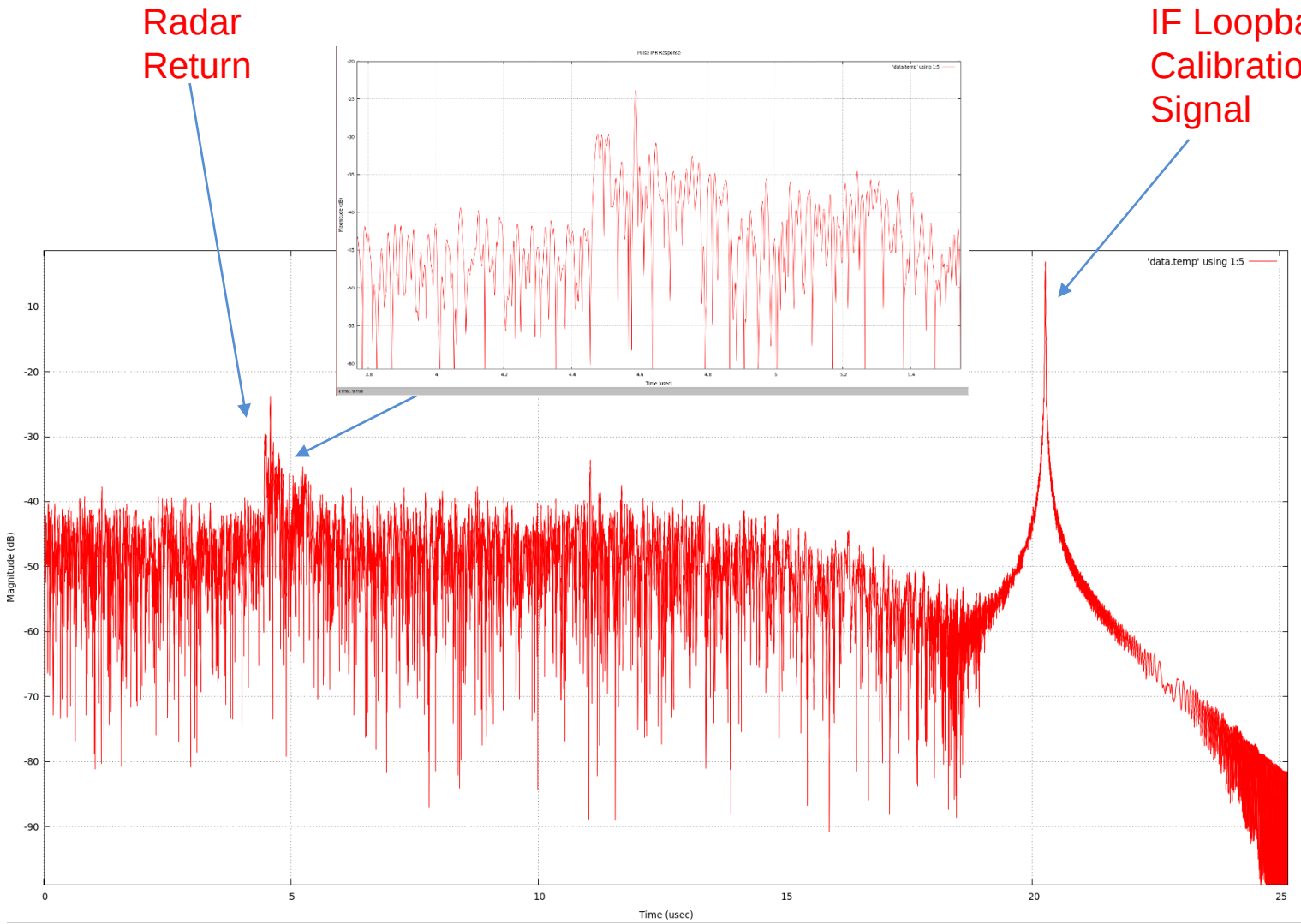
Many parameters are re-configurable

- Pulse duration
- PRF
- Bandwidth

SAR images formed via post-processing algorithms

Parameter	Value	Units
Platform Altitude	457 (1500), 914 (3000, 1524 (5000)	meters (feet)
Platform Speed	50	m/sec
X-Band Center Frequency	9.75	GHz
Lower Ku-Band Center Frequency	13.6	GHz
Upper Ku-Band Center Frequency	17.2	GHz
Transmit Bandwidth (LFM)	200.0	MHz
Pulse Repetition Frequency	1250	Hz
Ground Range Resolution	1.0	m
Azimuth Resolution	1.0	m

Example of Matched Filter Output



Six-Channel Raw Data Chart

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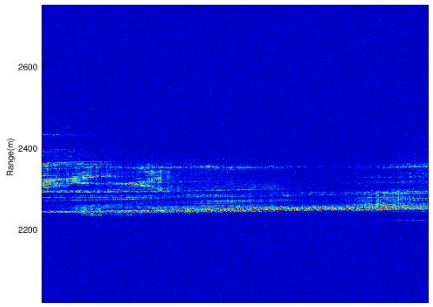
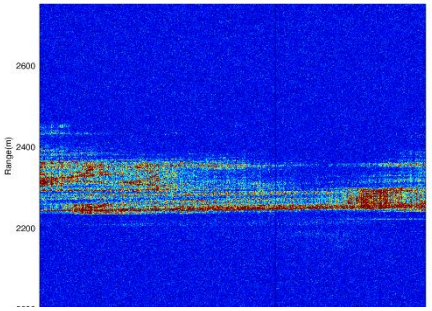
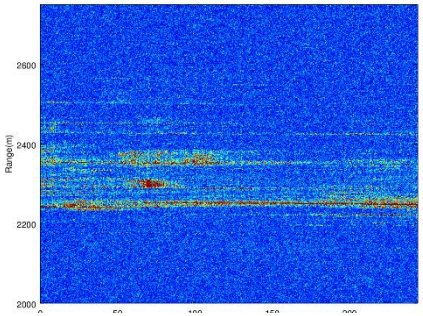
Ku-HPol



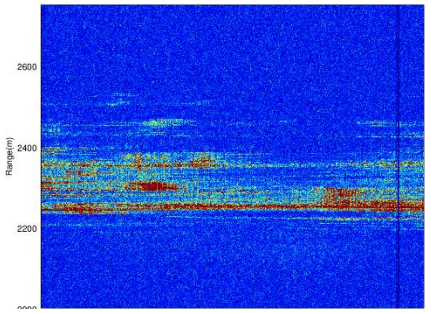
Ku-VPol



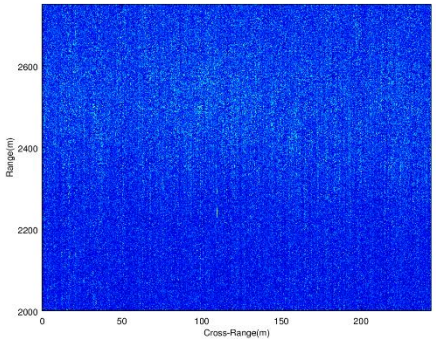
X-HPol



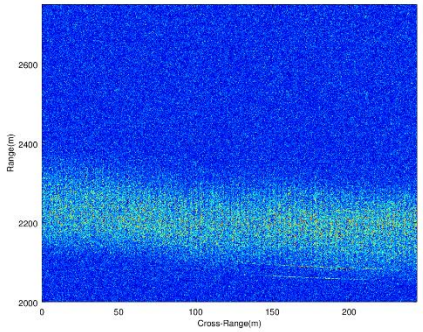
X-VPol



Ku-HPol

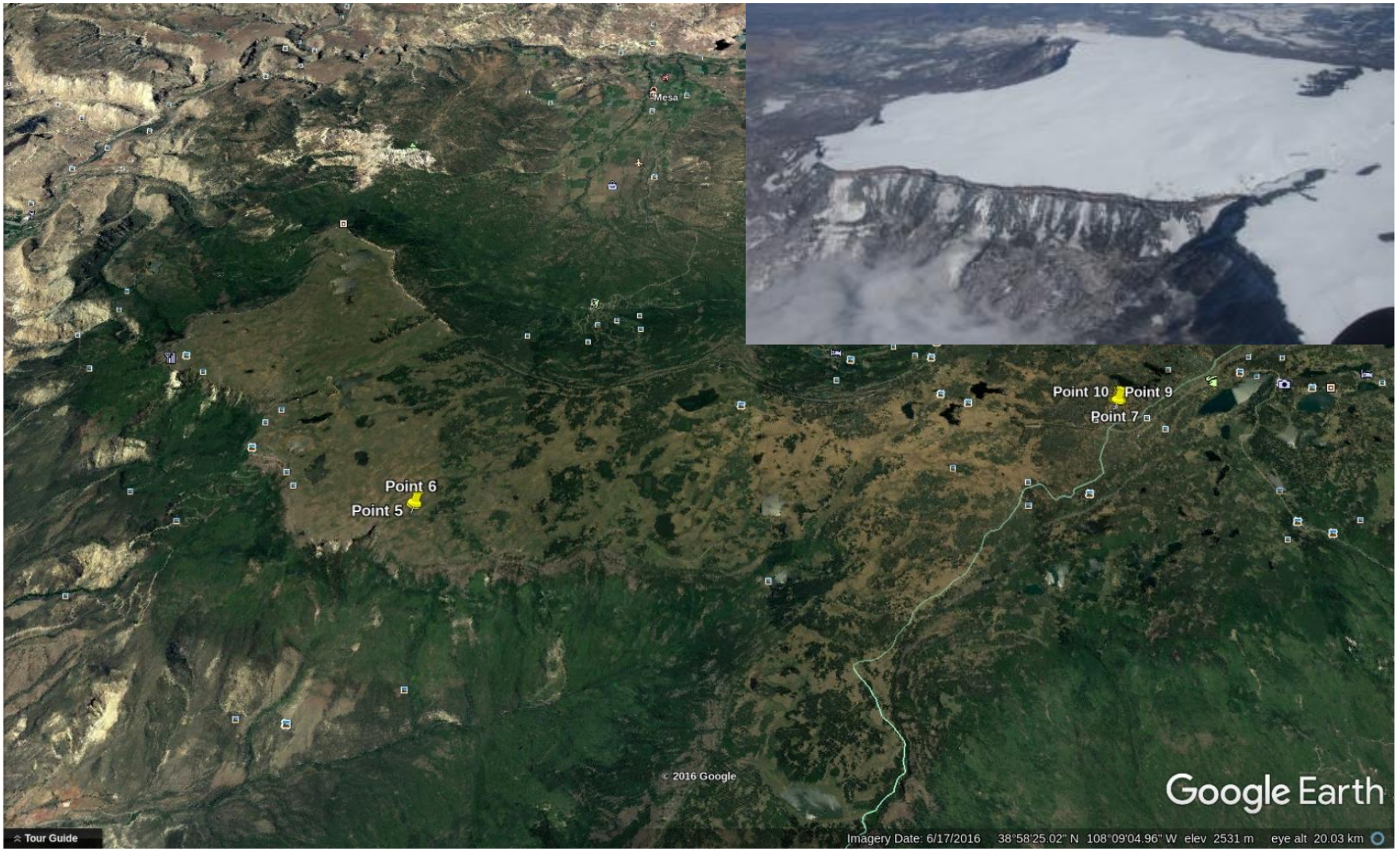


Ku-VPol



Similarity of data across all channels indicates proper operation
Cross pol is lower than co pol as expected

Grand Mesa Radar Target Locations



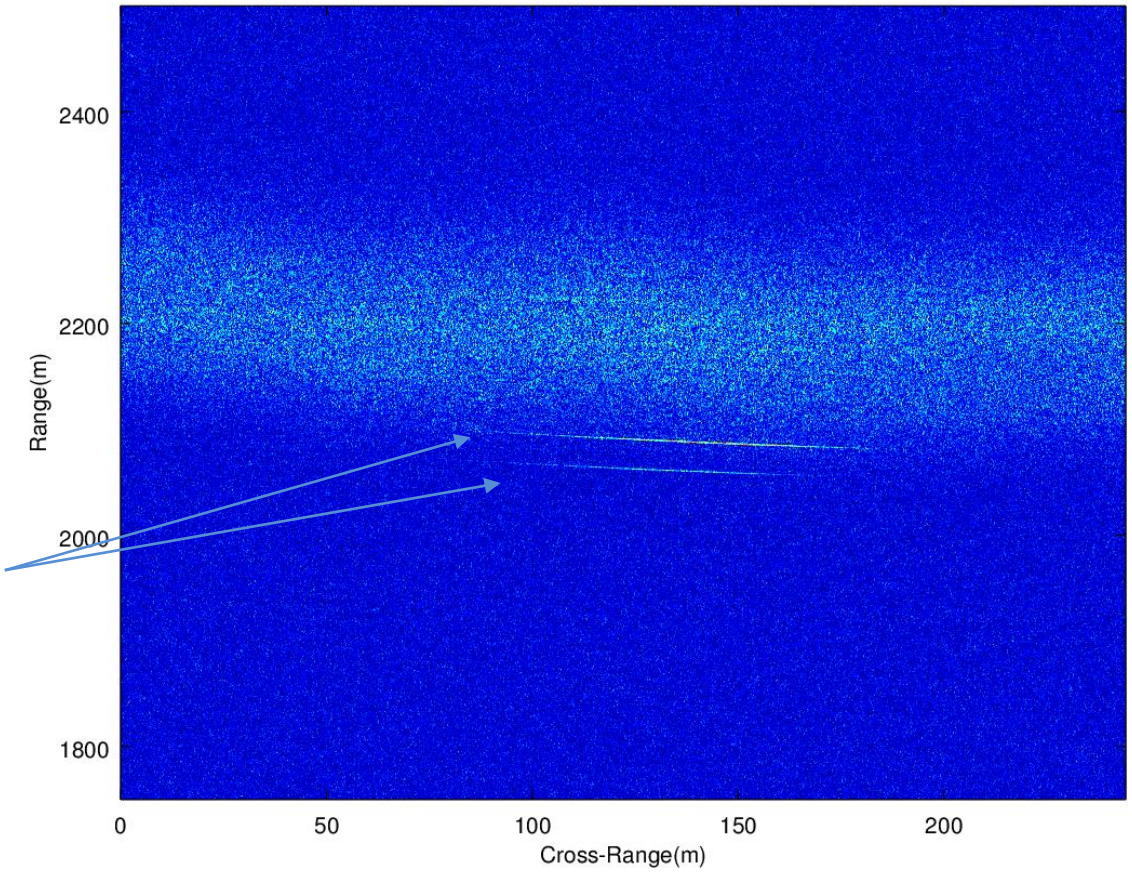
Western Mesa Radar Targets

Radar Target 6

Radar Target 5

Corner Reflectors Visible on Google Earth

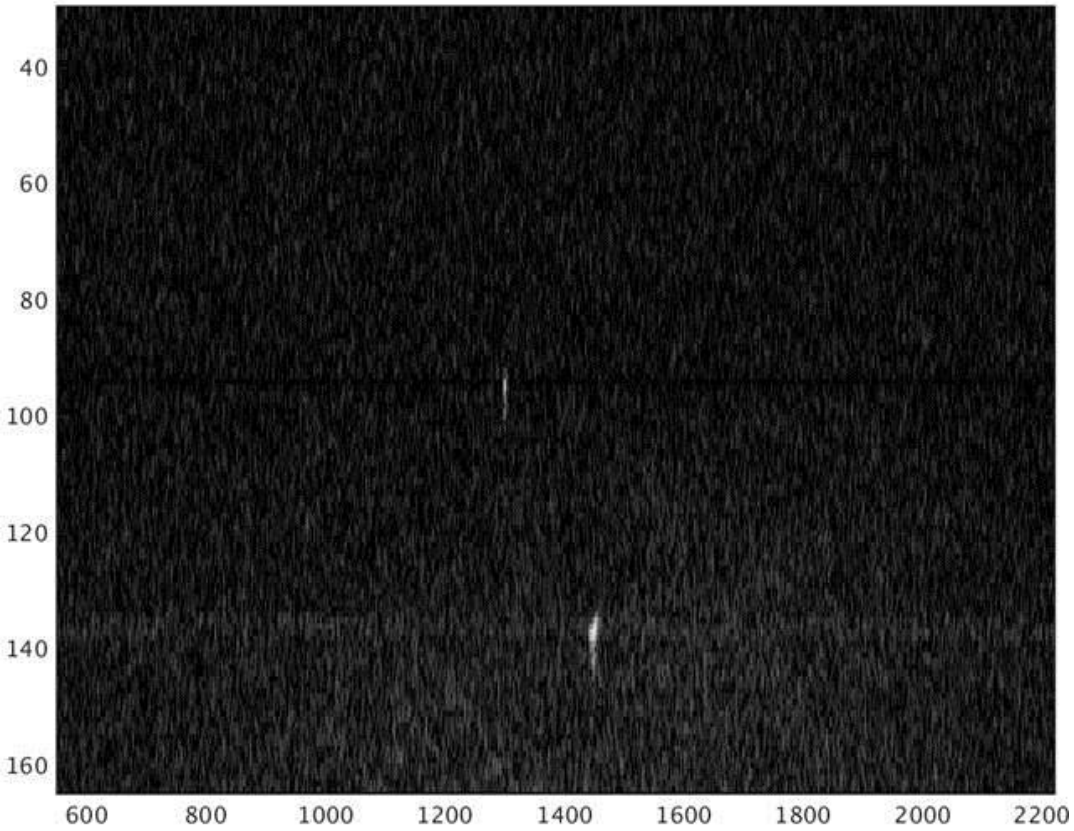
Western Mesa Radar Targets - Range Only Processing



Corner Reflector Returns

Distance Between Reflectors is Correct in Range

Western Mesa Corner Reflectors - Unfocused SAR Image



Two Corner Reflectors Clearly Visible at Correct Locations
Meets 10m Resolution Requirement

Summary and Conclusions

Groundbreaking antenna fabrication technology represents state of the art in integrated millimeter-wave wideband arrays

- Reduces SWAP-C for the ultimate space application

Combined multi-band radar and radiometry using a single aperture has been proven

- Radiometer data from all three campaigns
- Radar data from last campaign

SAR is nearing readiness for extended science campaigns

- Processing of data from last campaign is still under way
  - An INS issue may limit quality of results for SAR
  - Radar data itself appears to be of science quality

Campaign planned for November 2017 expected to resolved remaining issues